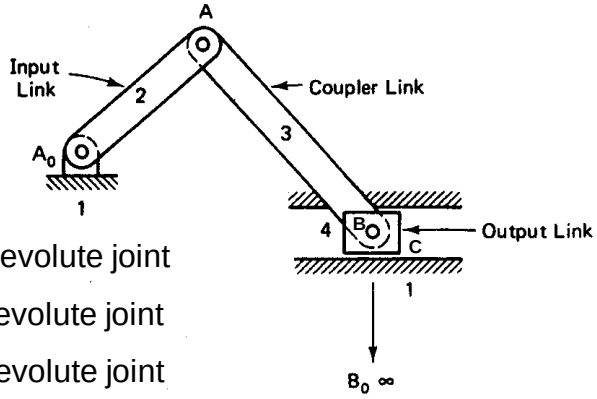
Chapter 5
Mechanisms with higher pairs and other problems in the theory of mechanisms

- Slider-crank Mechanism - Equivalence of Higher Order Joints
- Cam Mechanisms
- Parasitic motions
- Passive elements in linkages

Slider-Crank mechanism: in the family of “four-bar” mechanism with one link regarded as infinitely long



A_0 = {1,2} revolute joint

A = {2,3} revolute joint

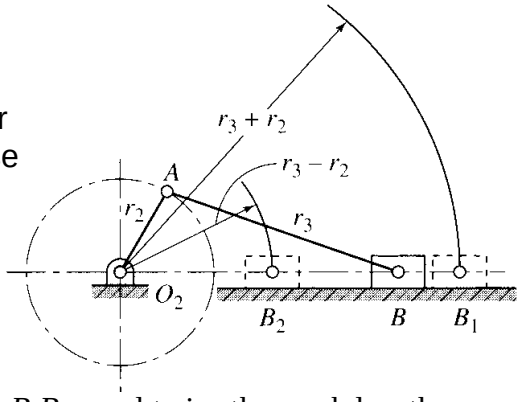
B = {3,4} revolute joint

C = {1,4} prismatic joint

Slider-Crank Mechanism (remember)

In-line slider crank mechanism

The line of travel of the hinged joint of the slider passes through the base joint of the crank.

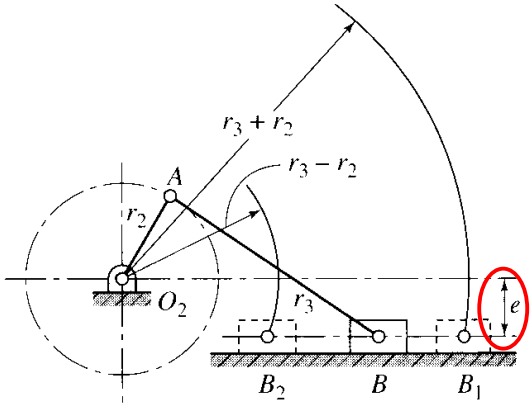


The mechanism has a stroke B_1B_2 equal twice the crank length r_2.

Locations B_1 and B_2 are called the extreme positions (limiting) of the slider

Slider-Crank Mechanism (remember)

Offset slider-crank mechanism



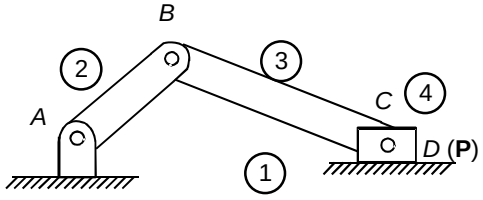
Extreme positions of offset slider-crank mechanism are obtained by intersections between arches with minimum radius $R_{min} = r_3 - r_2$ and maximum radius $R_{max} = r_3 + r_2$ with line of slider travel, respectively. Generally slider has a kinematic dimension too (represented usually by a vertical bar) so that the joint B to be not located at e distance.

Classifications of pairs (remember)

- From kinematics point of view kinematic pairs are classified in classes *k,* representing the number of restricted motions:
  - revolute, prismatic and helical pairs have $k = 5$;
  - cylindrical pairs have $k = 4$;
  - spherical and plane pairs have $k = 3$.
- From geometrical point of view (i.e. contact between the links) kinematic pairs are classified in:
  - lower pairs in case of surface contacts (linkages mechanisms);
  - higher pairs in case of point or line contacts (cam and gear mechanisms).

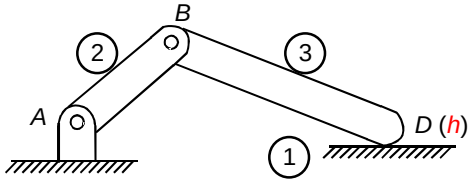
Equivalence of Higher Order Joints

A = {1,2} revolute joint
B = {2,3} revolute joint
C = {3,4} revolute joint
D = {1,4} prismatic joint



$$M_3 = 3\,m - 2\,l_p - h_p = 3\times3 - 2\times4 - 0 = 1$$

A = {1,2} revolute joint
B = {2,3} revolute joint
D = {1,3} higher pair



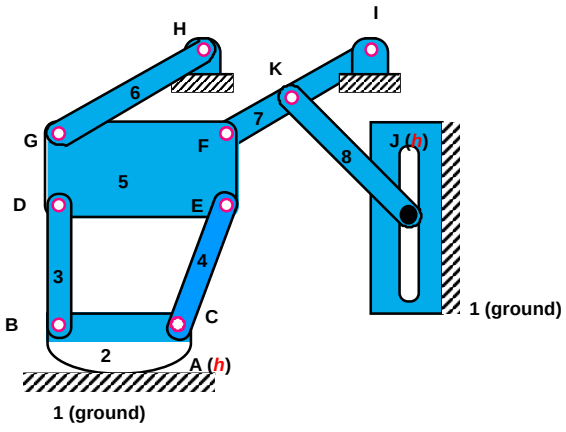
$$M_3 = 3\,m' - 2\,l_p' - h_p' = 3\times(3-1) - 2\times(4-2) - 1 = 1$$

Example of a plane mechanisms with higher pairs

Higher pairs:

A = {1,2}

J = {1,8}



$$M_3 = 3\,m - 2\,l_p - h_p = 3\times 7 - 2\times 9 - 2 = 1$$

$$M_3 = 3\,m' - 2\,l_p' - h_p' = 3\times (7+2) - 2\times (9+4) - 0 = 1$$

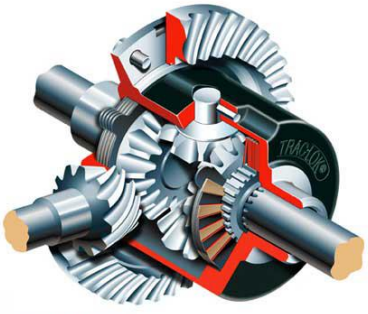
Clasiffication of mechanisms

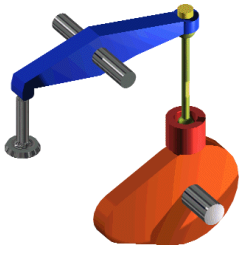
- Linkage mechanisms
- Screw mechanisms

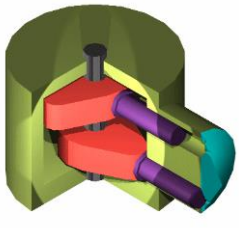
lower pairs

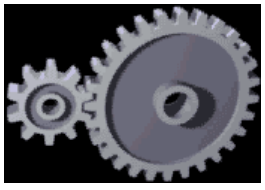
- Cam mechanisms
- Gear mechanisms

higher pairs

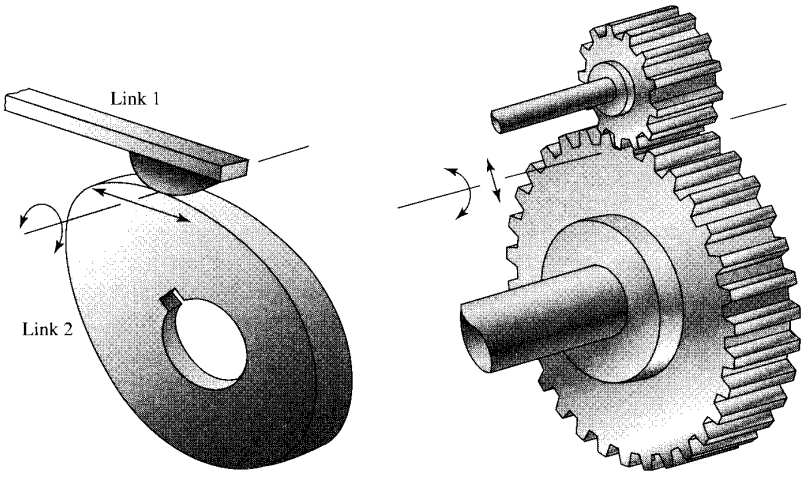








Higher Order Joints

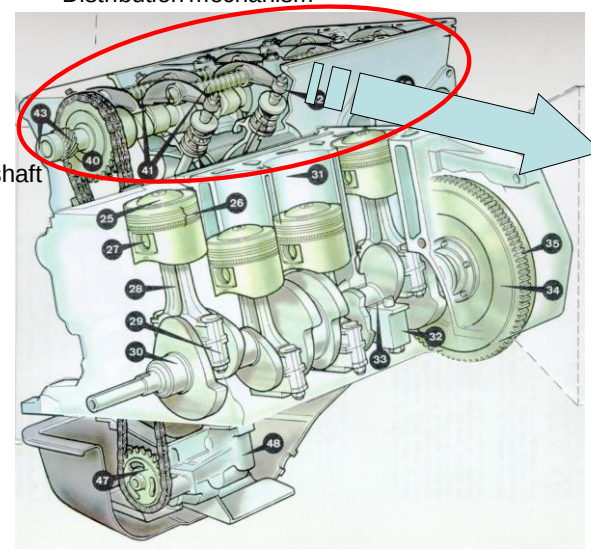


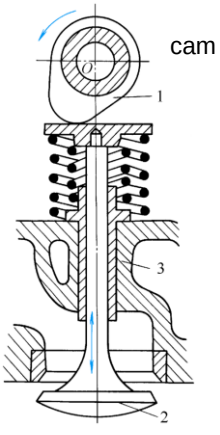
(a) Cam joint (b) Gear joint

Internal Combustion Engine

Distribution mechanism

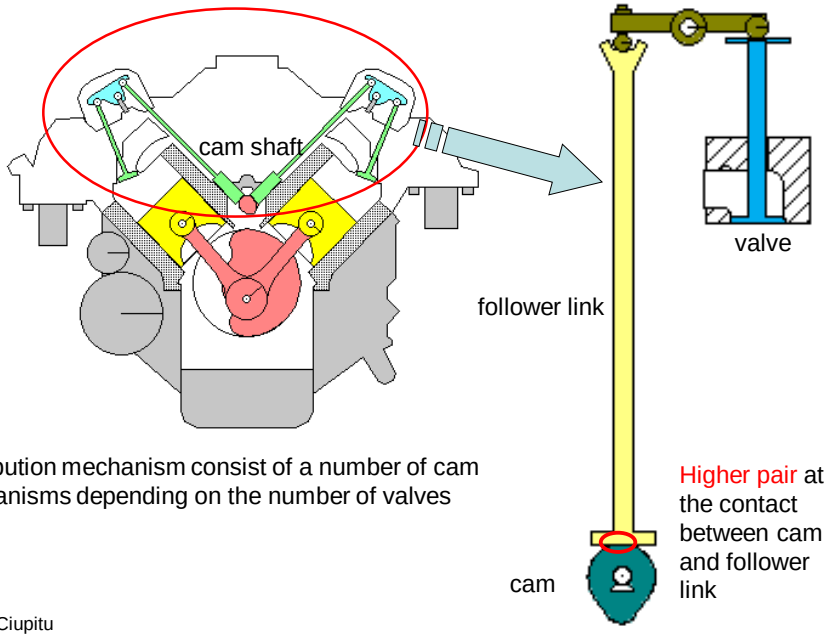
cam shaft





Cam mechanism

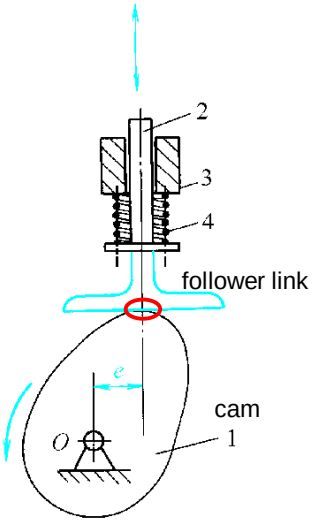
"V" Internal Combustion Engine

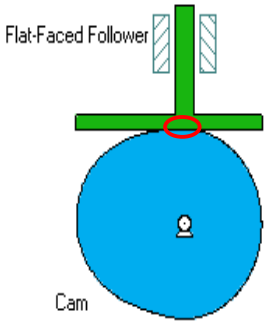


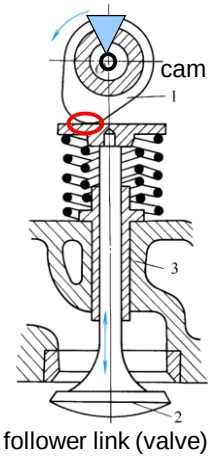
Distribution mechanism consist of a number of cam mechanisms depending on the number of valves

Higher pair at the contact between cam and follower link

Flat Follower Cams



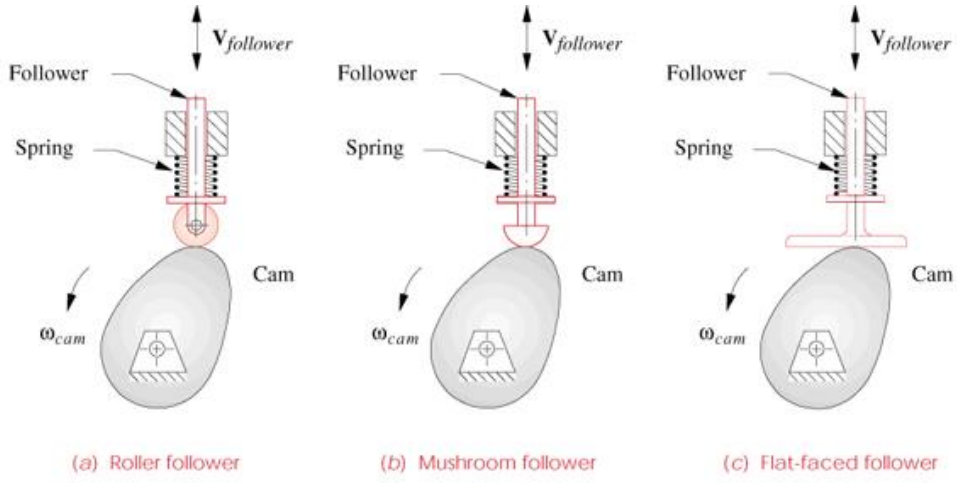




follower link (valve)

Higher pair at the contact between cam and follower link

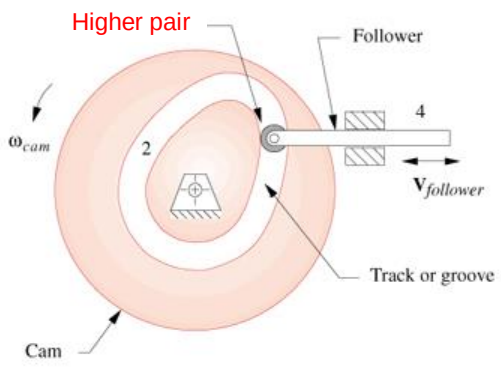
Rotating cams and translating followers



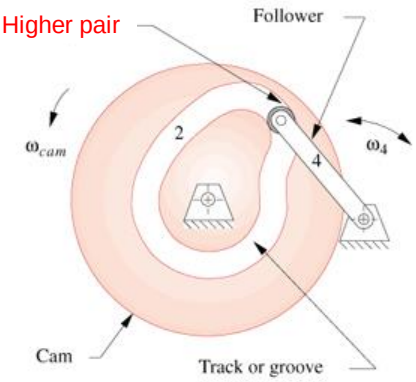
Classifications of pairs (remember)

- From constructional point of view kinematic pairs are classified in:
  - *form-closed pairs* (Ex.: revolute pair, prismatic pair in two-side slot, cylindrical pair, helical pair, cam mechanisms in which cam has a track);
  - *force-closed pairs* contact maintained by a force; usually the force of a spring (Ex.: prismatic pair in one-side slot, cam-follower higher pair, flat lower pair);
- From functional point of view kinematic pairs are classified in:
  - *active pairs* (pair variables are the generalised co-ordinates of mechanism);
  - *passive pairs* (pair variables are function of active pairs variables).

Form-closed Cams

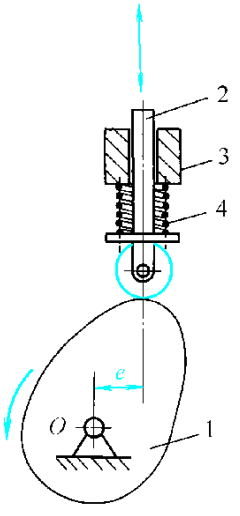


(a) Form-closed cam with translating follower

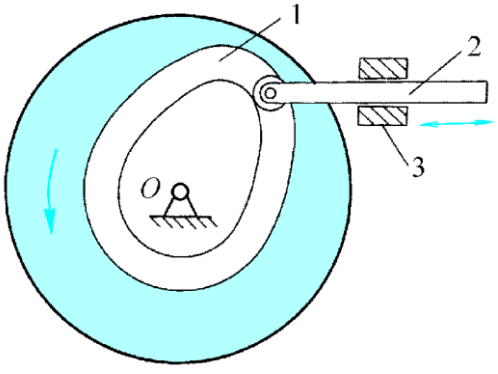


(b) Form-closed cam with oscillating follower

Roller Follower Cams

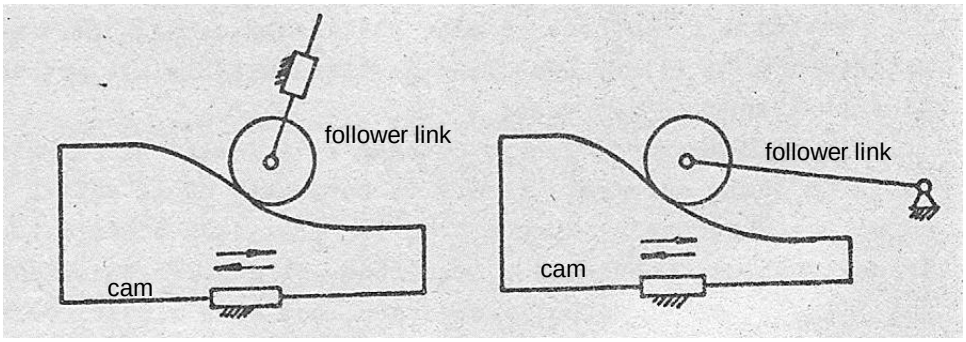


Higher pair maintained by the force of a spring



Higher pair maintained by the form of a track on the cam

Translating Cams

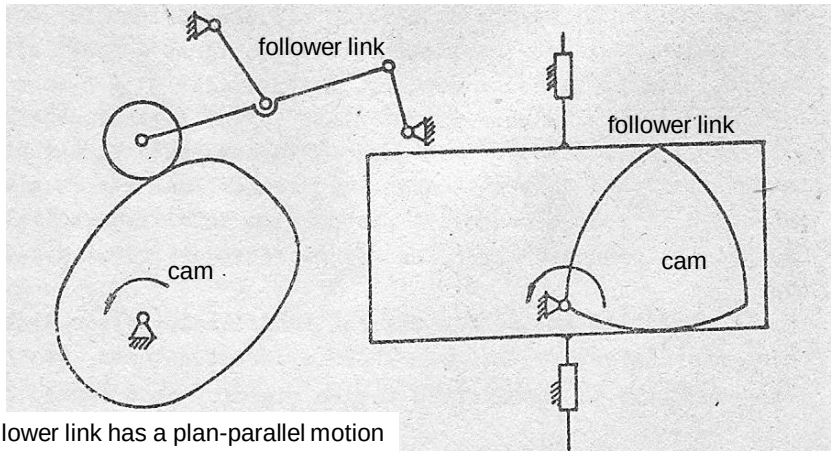


Follower link with sliding motion and roll

Follower link with rotating motion and roll

Attention: Identify all joints of these mechanisms ! Start counting of element by ground with 1. Denote lower and higher joints in the format:
Joint name = {first element number, second element number} and write about each joint the type of it according to the joint classification criteria

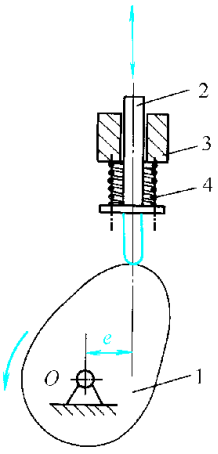
Special Cam Mechanisms

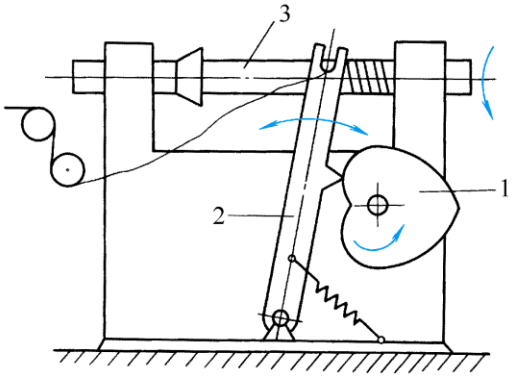


Follower link has a plan-parallel motion

Attention: Identify all joints of these mechanisms ! Start counting of element by ground with 1. Denote lower and higher joints in the format:
Joint name = {first element number, second element number} and write about each joint the type of it according to the joint classification criteria

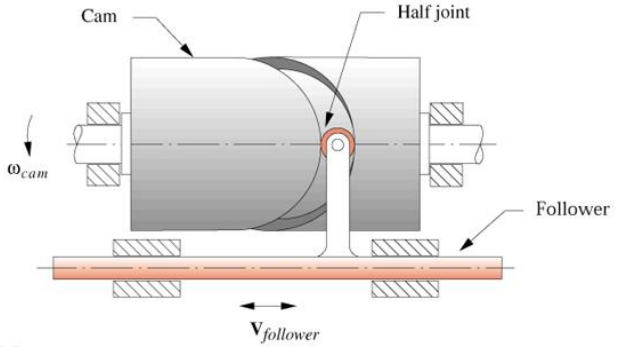
Knife-edge Follower Cams

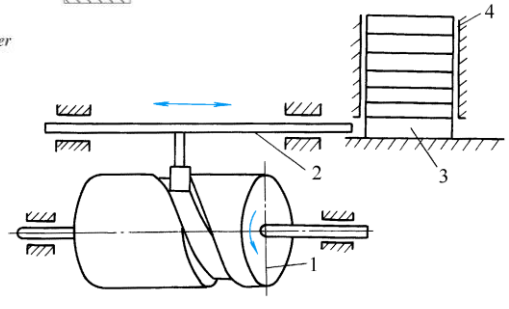




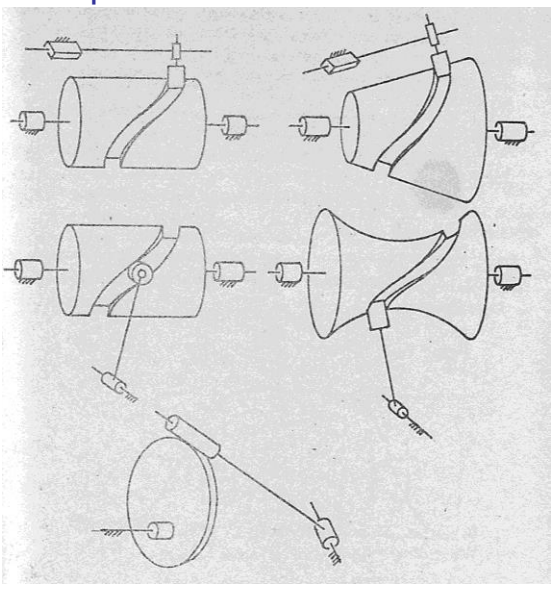
Winding machine

Cylindrical Cam Mechanism

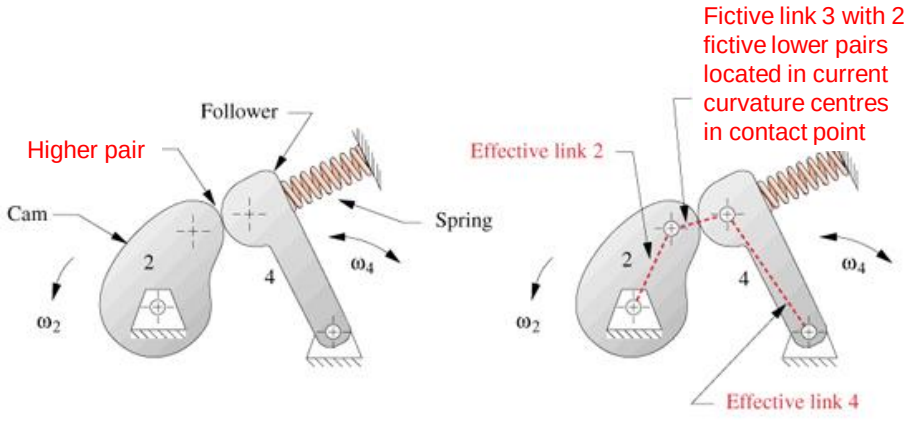




Spatial Cam Mechanism



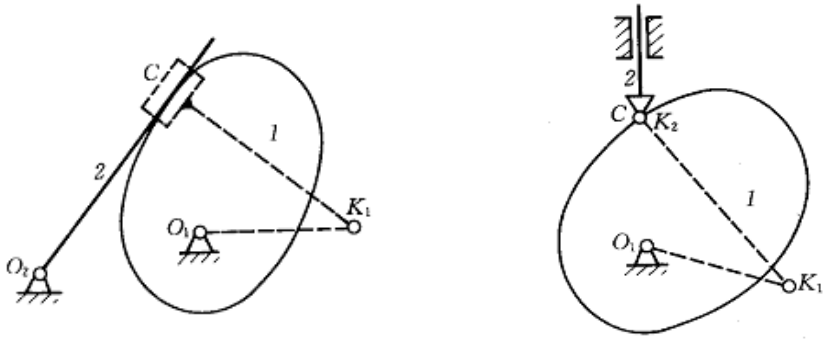
Oscillating Cam-Follower



(a) An oscillating cam-follower has an effective pin-jointed fourbar equivalent

Observation: Equivalent mechanism is a four-bar mechanism !

Degrees of freedom and equivalence of higher pairs



$$M_3 = 3\,m - 2\,l_p - h_p = 3\times 2 - 2\times 2 - 1 = 1$$

After equivalence:

$$M_3 = 3\,m' - 2\,l_p' - h_p' = 3\times 3 - 2\times 4 - 0 = 1$$

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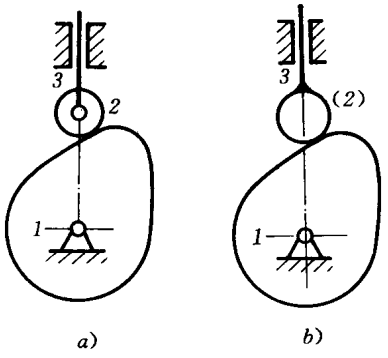
Degrees of freedom – uncontrolled motions (parasitic motions)

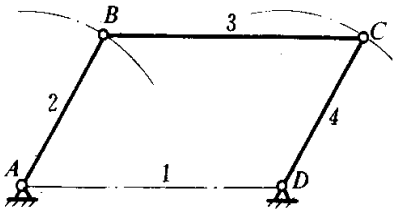


$$M_{3,a)} = 3\,m - 2\,l_p - h_p = 3\times 3 - 2\times 3 - 1 = 2\ !$$

$$M_{3,b)} = 3\,m' - 2\,l_p' - h_p' = 3\times 2 - 2\times 2 - 1 = 1$$

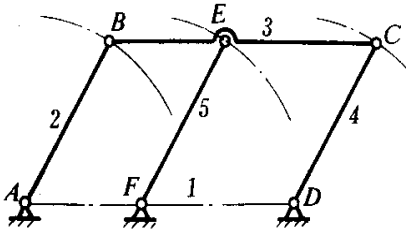
Observation: Motion of roll 2 does not change the position and the function of cam mechanism !

Passive elements in linkages



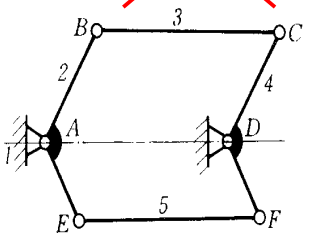
$M_3 = 3\,m - 2\,l_p - h_p$

$= 3\times3 - 2\times4 - 0 = 1$



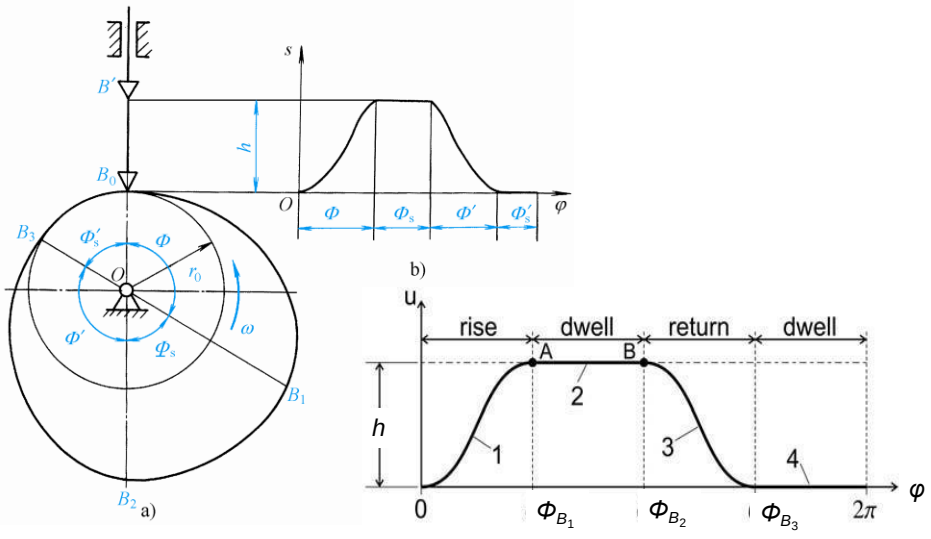
$M_3 = 3\,m - 2\,l_p - h_p$

$= 3\times4 - 2\times6 - 0 = 0$

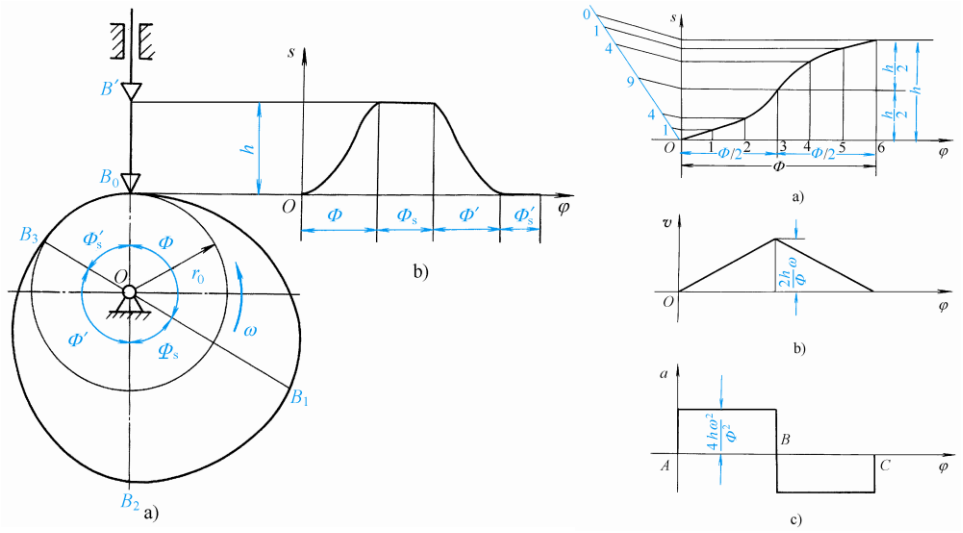


Observation: Supplementary element 5 does not change the functioning of parallelogram mechanism which remain to have only one degree of mobility !

Functioning phases of Cam mechanisms

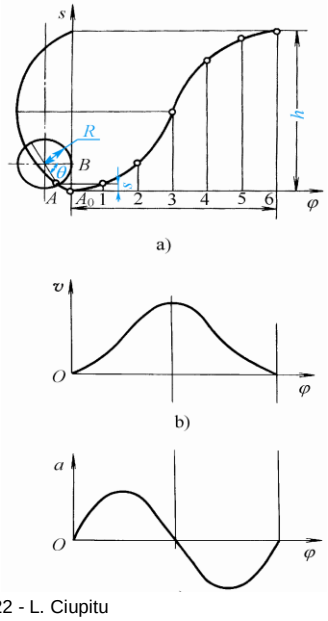


Synthesis of motion laws



Motion law during the raising phase

Synthesis of motion laws



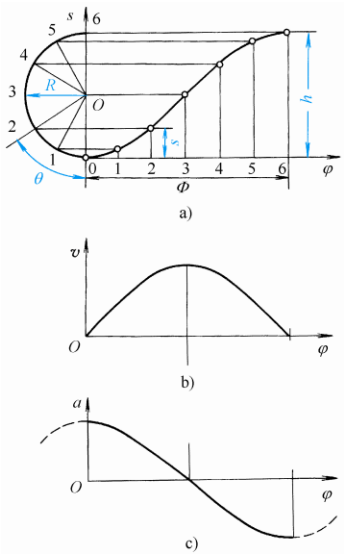
Example 1 of "sine" motion law type:

$$s = h[\frac{\varphi}{\Phi} - \frac{1}{2\pi}\sin(2\pi\frac{\varphi}{\Phi})]$$

$$v = \frac{h\omega}{\Phi}[1-\cos(2\pi\frac{\varphi}{\Phi})]$$

$$a = \frac{2\pi h\omega^2}{\Phi^2}\sin(2\pi\frac{\varphi}{\Phi})$$

Synthesis of motion laws



Example 2 of "cosine" motion law type

$$s = \frac{h}{2}[1 - \cos(\frac{\pi}{\Phi}\varphi)]$$

$$v = \frac{\pi h\omega}{2\Phi}\sin(\frac{\pi}{\Phi}\varphi)$$

$$a = \frac{\pi^2 h\omega^2}{2\Phi^2}\cos(\frac{\pi}{\Phi}\varphi)$$

Conclusions

- Higher pairs are used in many types of mechanisms, not only to geared and cam mechanisms;
- A higher pair could be equivalate by a fictive element and 2 fictive lower pairs between this fictive element and the 2 elements which are in contact into the higher pair;
- Cam mechanisms are irreversible mechanisms and the motion of cam and of follower link could be mainly:
  - of rotational type
  - of translational type
- Cam mechanisms are used in order to obtain a specific given motion low of output element which is the follower link. This is a synthesis problem.